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CRSC Report 82-4

CENTER FOR REMOTE SENSING AND CARTOGRAPHY

UNIVERSITY OF UTAH
RESEARCH INSTITUTE

Detection of Aspen-Conifer Forest Mixes from Landsat Digital Data

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ABSTRACT

Aspen, conifer and mixed aspen/conifer forests have been mapped for a 15-quadrangle study area in the Utah-Idaho Bear River Range using Landsat multispectral scanner data. Digital classification and statistical analysis of Landsat data allowed the identification of six groups of signatures which reflect different types of aspen/conifer forest mixing. Photo interpretations of the print symbols suggest that such classes are indicative of mid to late seral aspen forests. Digital print map overlays and acreage calculations were prepared for the study area quadrangles. Further field verification is needed to acquire additional information about the nature of the forests which have been examined via remote sensing. This study suggests that single date Landsat analysis will be a cost effective means to index aspen forests which are at least in the mid seral phase of conifer invasion. Since aspen canopies tend to obscure understory conifers for early seral forests, a second date analysis, using data taken when aspens are leafless, could provide information about early seral aspen forests.

ACKNOWLEDGMENTS

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INTRODUCTION

Forests of quaking aspen (Populus tremuloides Michx.) are considered to be predominantly subclimax plant communities in the Rocky Mountain Region (Mueggler 1976; Bartos 1973). Mature aspen forests are most often replaced by evergreen conifers (Abies spp., Picea spp., Pseudotsuga spp., or Pinus spp.) unless some form of major disturbance occurs such as fire, disease, or clearcutting. When an overstory is thus destroyed, prolific root sprouting of aspen generally is initiated and aspen regains dominance on the site. In many areas where natural fires have been curtailed and logging has not occurred, former aspen stands are now dominated by coniferous species. More than 4.1 million acres of commercial aspen forests (Green and Setzer 1974), and possibly an additional 1.5 million acres of noncommercial aspen lands, exist in the Rocky Mountains. Resource managers are concerned that succession of sizable portions of these forests to conifers will have adverse impacts on the water, wildlife habitat, and livestock forage values of the aspen type.

The Intermountain Forest and Range Experiment Station is interested in developing research techniques which combine the use of remote sensing technology and ground truth data to study and map the extent of stable and seral aspen forests in the Intermountain area. The overstory attributes of aspen forests in various successional phases and changes in understory characteristics produced by conifer invasion of aspen, are expected to produce distinctive spectral responses; the ability to detect such variations in aspen forests will be a valuable tool for inventorying aspen and associated range, wildlife and watershed attributes. Forest managers need to have a means to assess the extent to which aspen stands are being

converted to coniferous forests as part of the process of developing forest management plans. The application of Landsat digital processing methods suggests a relatively quick and inexpensive means to address the problems associated with the succession process on a forest, ranger district, or planning unit basis.

Since the initial launch in July 1972, the NASA series of Landsat satellites has provided a valuable means of analyzing and mapping earth resources. Landsat data are derived from a satellite which, while orbiting the earth at an altitude of 570 miles in a near polar pattern, collects radiance values in four spectral bands of light on the electromagnetic spectrum via a multispectral scanner (MSS). The bands sensed by the MSS are numbered four, five, six, and seven, which correspond to electromagnetic wavelengths for visible green, visible red, and two near infrared light bands, respectively. The data are available in the form of computer compatible tapes (CCT) that have the radiance values for all picture elements (pixels) in all four bands. Each pixel represents approximately a 1.1 acre piece of the earth's surface.

The raw digital data may be processed using a variety of computer programs which have been developed to enhance visual contrasts, classify pixels, etc. The programs used at CRSC combine similar radiance value curves on all four bands for the pixels into "light signatures". Each signature is a class that represents light radiance values for different types of ground cover. Each pixel is then classified according to which light signature it best matches, and digitally classified maps are then field checked to determine map accuracy. Thus, Landsat data provides a unique means of analyzing environmental features which is often cost-effective where a high degree of resolution is not required for management purposes.

The study objective has been to utilize Landsat digital MSS data to devise quantitative indices which correlate with apparently stable and seral aspen forests, and use such indices to map and determine aerial coverage of several classes of stable/seral aspen forests in the Bear River Range of Idaho and Utah. This study has explored the extent to which a single date Landsat analysis may permit the delineation of different categories of aspen/conifer forest mix.

A recently completed study (Merola and Jaynes 1982) of aspen forests in the Bear River Range suggested that tree canopy characteristics and physical site factors (e.g., slope, soil moisture) are most likely to be correlated with light signatures derived from Landsat data. Although that study suggested that some understory characteristics were also correlated with Landsat classes, it is believed that such correlations stem from the fact that understory components reflect general forest and site conditions and not as a result of Landsat's ability to "see" the understory. However, Landsat light signatures for forests which have a relatively open canopy will be influenced more significantly by the understory features which are visible to the satellite's MSS. A study by Tom and Miller (1980) supports the conclusion above; those researchers found that digital topographic data significantly enhances the ability of MSS data to index and map forest site quality. However, a more recent study by Mayer and Fox (1981) concluded that detailed examination and calibration of MSS signatures could be used effectively in identifying coniferous forest species, tree size class, and forest crown closure. Such results, as well as other research efforts reviewed in Mayer and Fox (1981), offer encouragement that careful study of MSS data can be a cost-effective means of revealing the type of forest information sought in the present study.

STUDY AREA

This study has focused on the application of techniques for Landsat forest mapping on nearly 500,000 acres in the Bear River Range of Utah and Idaho. Figure 1 shows the fifteen U.S.G.S. topographic quadrangles (scale 1:24,000) for which map overlays have been prepared.

METHODS

The analysis and mapping performed in this study were accomplished at the facilities of the Center for Remote Sensing and Cartography, using digital data obtained from NASA's Landsat III satellite. The data necessary for the study, a computer compatible tape (CCT) recorded July 2, 1979, was already available at the Center. For data processing, the Center was able to utilize the "ELAS" package of computer software routines, developed by NASA's Earth Resources Laboratory in Missouri, which is operational on the University of Utah Research Institute's PRIME computer.

A brief explanation of the nature of the data contained on CCT's follows. Each Landsat scene represents a huge matrix of individual cells called picture elements or "pixels", for which radiance values are recorded. Each scene contains over ten million pixels; each pixel represents an area which is approximately 56m by 79m (ca. 1.1 acre). The satellite's multispectral scanner (MSS) records light reflectance values for the combined land cover or terrain features contained within each pixel. Reflectance values for four light spectral bands, two in the visible and two in the non-visible near infrared portions of the electromagnetic spectrum, are electronically relayed to earth receiving stations. The wavelengths corresponding to each band are as follows:

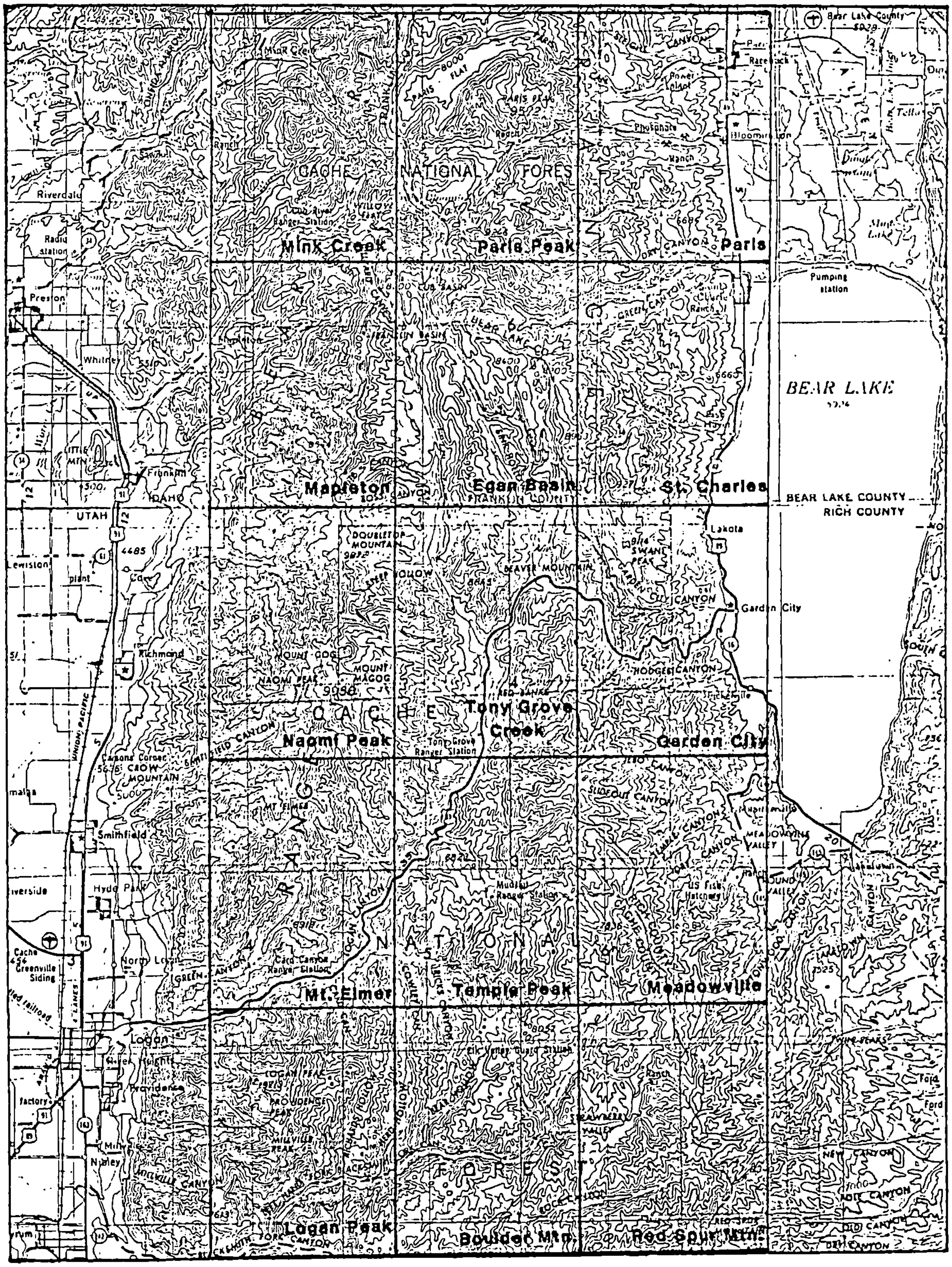
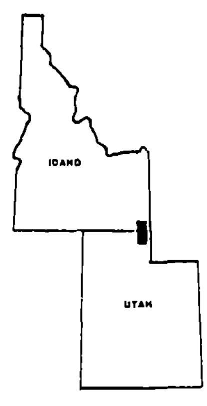


Figure 1. Locator map for the fifteen quadrangle study area in the Bear River Range.



Band 4 (green light)	500-600 nanometers (10^{-9}m);
Band 5 (red light)	600-700 nanometers;
Band 6 (near infrared)	700-800 nanometers;
Band 7 (near infrared)	800-1100 nanometers.

The digital processing of Landsat data is performed to use MSS values for each pixel in classifying pixels of similar spectral characteristics into groups or classes, which can then be correlated with field data or "ground truth". The primary rationale for performing digital processing of MSS data has been stated by Hutchinson (1982), as follows:

> "The argument made for digital multispectral classification is that, when considering the spectrum as a whole, different objects have different patterns of reflection and emission. Further, it is assumed that these spectral patterns are sufficiently unique to make objects consistently distinguishable from one another using statistical classification techniques."

Although Landsat is a relatively inexpensive means of analyzing and inventorying large areas of vegetation resources, variability of objects within a single multispectral classification may be quite high (Todd, et al. 1980). For this reason, efforts to increase resolution, and, more importantly, efforts to use ancillary data (e.g., digital topographic data) to improve classifications are being performed (Tom and Miller 1980). As noted above, however, this study explores the utility of analyzing only spectral reflectance data to accomplish the objective.

Raw Landsat data must first be reformatted to make them compatible with processing hardware. Next, the digital data are geographically corrected to remove the effects of earth curvature, spin, etc. (See Stage 1 of Figure 2.)

LANDSAT DIGITAL DATA ANALYSIS: STAGES 1 AND 2

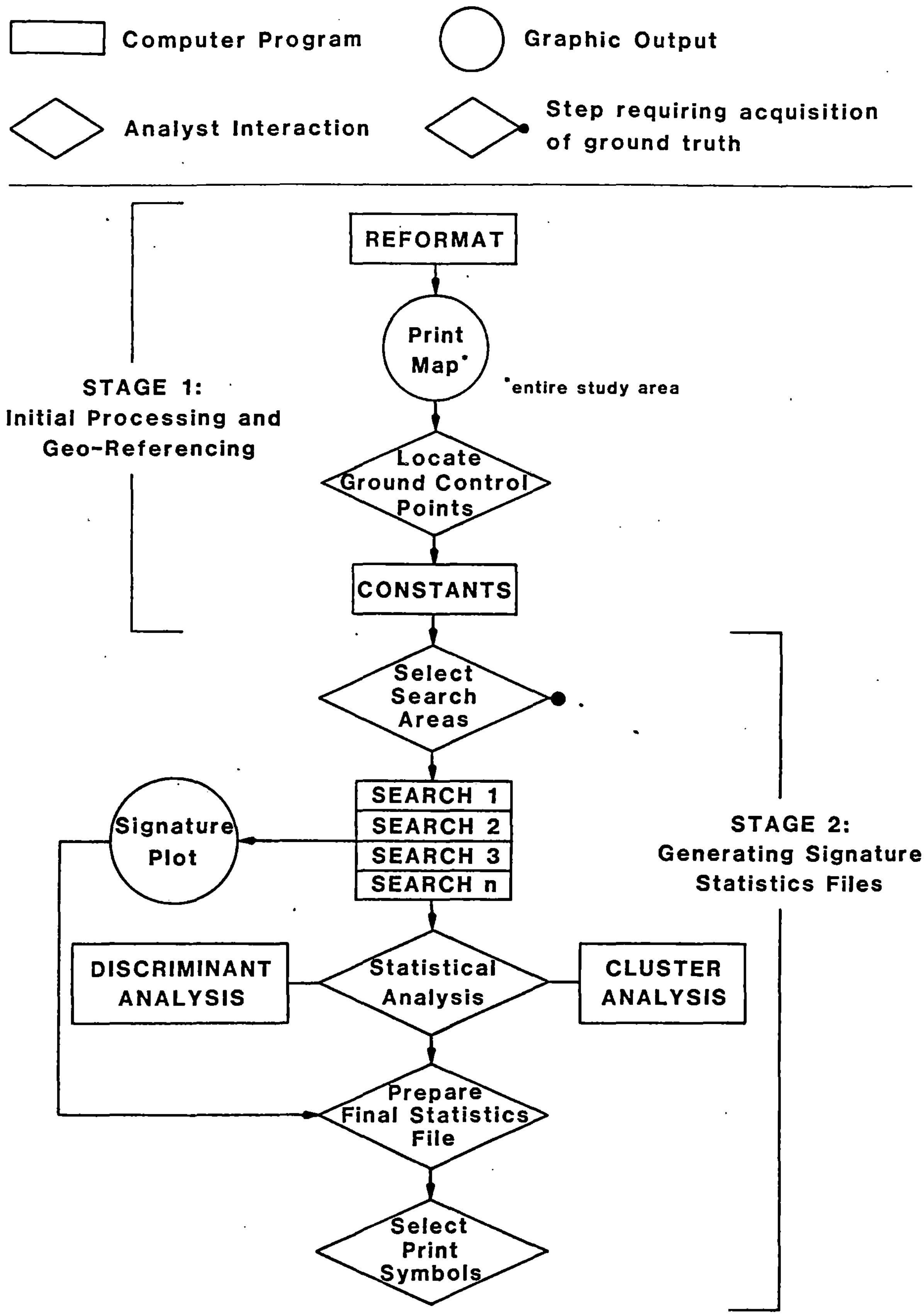


Figure 2. Summary of steps in Landsat digital data analysis: Stages 1 and 2.

Thereafter, a program called "SEARCH" is utilized to generate statistics which characterize pixel groups having similar spectral features across the four bands. (See Stage 2 of Figure 2.) SEARCH is a routine which is used to provide training statistics for a program called "MAXL", which classifies individual pixels into groups based upon each pixel's highest statistical probability of belonging to a given group. Initially, several blocks of data or "windows" within the Landsat scene were selected for the purpose of finding representative spectral signatures for forest classification in the study area; areas thus selected were known to contain the representative aspen, conifer, and aspen/conifer forest mixes of interest.

Once the study windows are selected, the program SEARCH examines each contiguous six scan line (Landsat pixel matrix "row") by six element block (pixel matrix "column"); if the spectral data within the six by six block are too heterogeneous, the program will switch to the use of a three by three block of pixels. The statistics generated by SEARCH include mean pixel light radiance values for each of the four bands, a covariance matrix, and a priori values. A set of statistics is generated by SEARCH representing various classes of light reflectance patterns found in the study area "searched". The four mean light reflectance values, one for each MSS band, are plotted to form a curve called a "light signature" which characterizes each class. SEARCH thus "trains" MAXL to recognize different ground cover patterns as it places individual pixels into classes. A knowledge of the manner in which different land cover features form spectral signatures, combined with the analysis of aerial photography and field checking of digital classifications, allows remote sensing researchers to provide an interpretation of Landsat-derived classes.

In this study, the SEARCH program produced sixty-seven signatures; further efforts were directed toward finding those signatures which would most likely reflect different types of aspen/conifer forest habitat. Stage 2 of Figure 2 illustrates several of the steps utilized in making detailed studies of signatures. The signature plot, described above, permits a substantial amount of interpretation; spectral signature shape and magnitude of reflectance are diagnostic of land cover types. Generally, similarly shaped signature curves indicate similar cover types while upward or downward shifts of similar curves indicate differences in topography or amount of ground cover.

Spectral signatures are also studied statistically to detect similarities and differences. First, a principal components analysis of the mean values for each signature's four MSS bands reduces such data to factor scores for two components; typically bands 4 and 5 are combined into one component ("visible" light), and bands 6 and 7 combine to form the second ("infrared" light). Next the factor scores are used in a cluster analysis which groups spectral signatures according to a similarity index. Finally, the factor scores and group clusters are used in a discriminant analysis of the signatures. The two-dimensional scatter plot produced in the discriminant analysis allows one to receive a graphical view of signature relationships; the discriminant analysis scatter plot, with two axes representing the visible and infrared light components, may be divided into regions or groups of signatures that correspond to similar ground cover types. This process is a vital link in allowing an often unmanageable number of signatures to be combined into groups of similar signatures. This procedure allows the researcher

a great deal of flexibility in performing Landsat digital analysis; a large number of signatures are available and one may concentrate on the signatures of particular interest, while signatures of lesser interest may be grouped together. The use of discriminant analysis, based on MSS principal components and cluster analyses, in combination with examination of spectral signature plots and field experience has been a key element in achieving good results from the unsupervised approach to Landsat data analysis. Such analyses were performed for the signatures in this study and will be discussed below.

An additional and most vital dimension to the process of digital data analysis is calibrating spectral signatures with "ground truth". This is accomplished by assigning print symbols to each signature or signature group and printing maps which may then be registered to standard base maps or referenced to photographs and field study sites. In this study, digital print maps were prepared for representative U.S.G.S. 7½ minute quadrangles (scale 1:24,000): Paris Peak, Mink Creek, Egan Basin, Mt. Elmer, Tony Grove Creek, and Logan Peak. Calibration of spectral signatures with actual land cover types was accomplished primarily by use of U.S.G.S. orthophoto quadrangles, high altitude color infrared photography (i.e. NASA and National High Altitude Program photography), and low altitude Forest Service natural color photography. Over 100 photo sample sites selected mainly for aspen and aspen/conifer forest areas were located on the digital print maps; these same areas were identified on corresponding photography and interpreted with respect to forest type, canopy closure and understory vegetation (if the forest canopy was open or closed with forest openings). In addition, twenty-

six field study plots from a former study (Merola and Jaynes 1982) and U.S.G.S. topographic quads with twelve sample areas identified by personnel of the Intermountain Forest and Range Experiment Station from ground observations were also used in the signature calibration process. A reconnaissance trip through the study area was made to further familiarize the researchers with the nature of the vegetation being studied with Landsat data. The above-described process of interpreting and combining spectral signatures based upon signature curve similarity, discriminant analysis of the signatures and calibration of signature print symbols with photograph and ground observations is outlined in Stage 2 of Figure 2 and Stages 3 and 4 of Figure 3.

RESULTS AND DISCUSSION

The process of generating representative spectral signatures by SEARCH produced 67 signatures. Each pixel within the study area was then classified into one of the 67 signatures that had been generated. After these 67 signatures were reduced from four mean band reflectance values to two components, and clustered according to signature factor score similarity, a discriminant analysis was performed which created the scatter plot in Figure 4. Such figure depicts the spatial arrangement of signatures across a two-dimensional graph: the X-axis (discriminant function #1), represents a gradient of increasing visable light reflectance from left to right; the y-axis (discriminant function #2), represents a gradient of infrared light reflectance from bottom to top. Thus, signature #65 (upper right corner) is associated with unvegetated bright areas such as snow, clouds, or bare surfaces; signature #25 (upper left), is bright in infrared light reflectance but low in visable light reflectance

LANDSAT DIGITAL DATA ANALYSIS: STAGES 3 AND 4

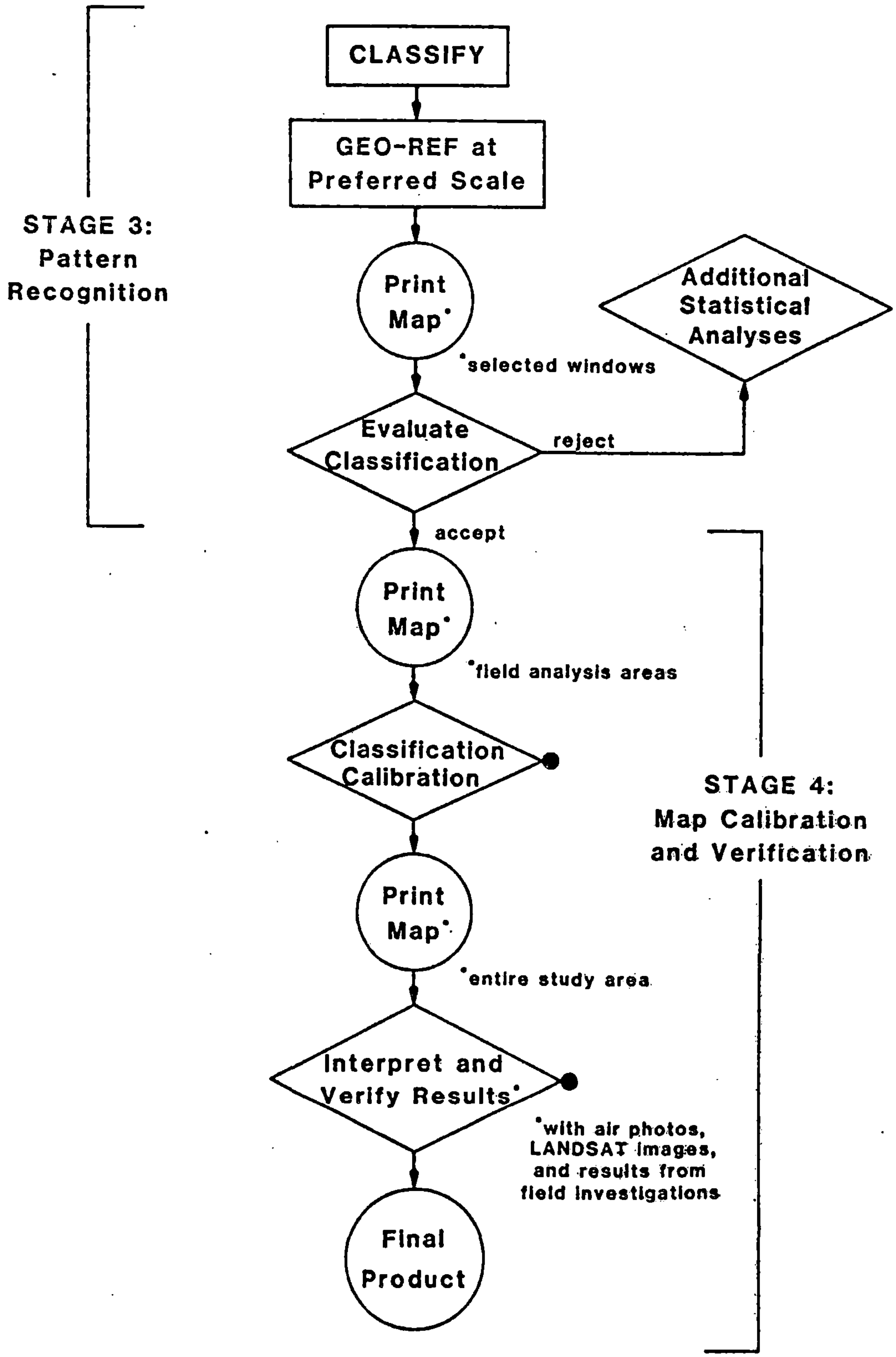


Figure 3. Summary of steps in Landsat digital data analysis: Stages 3 and 4.

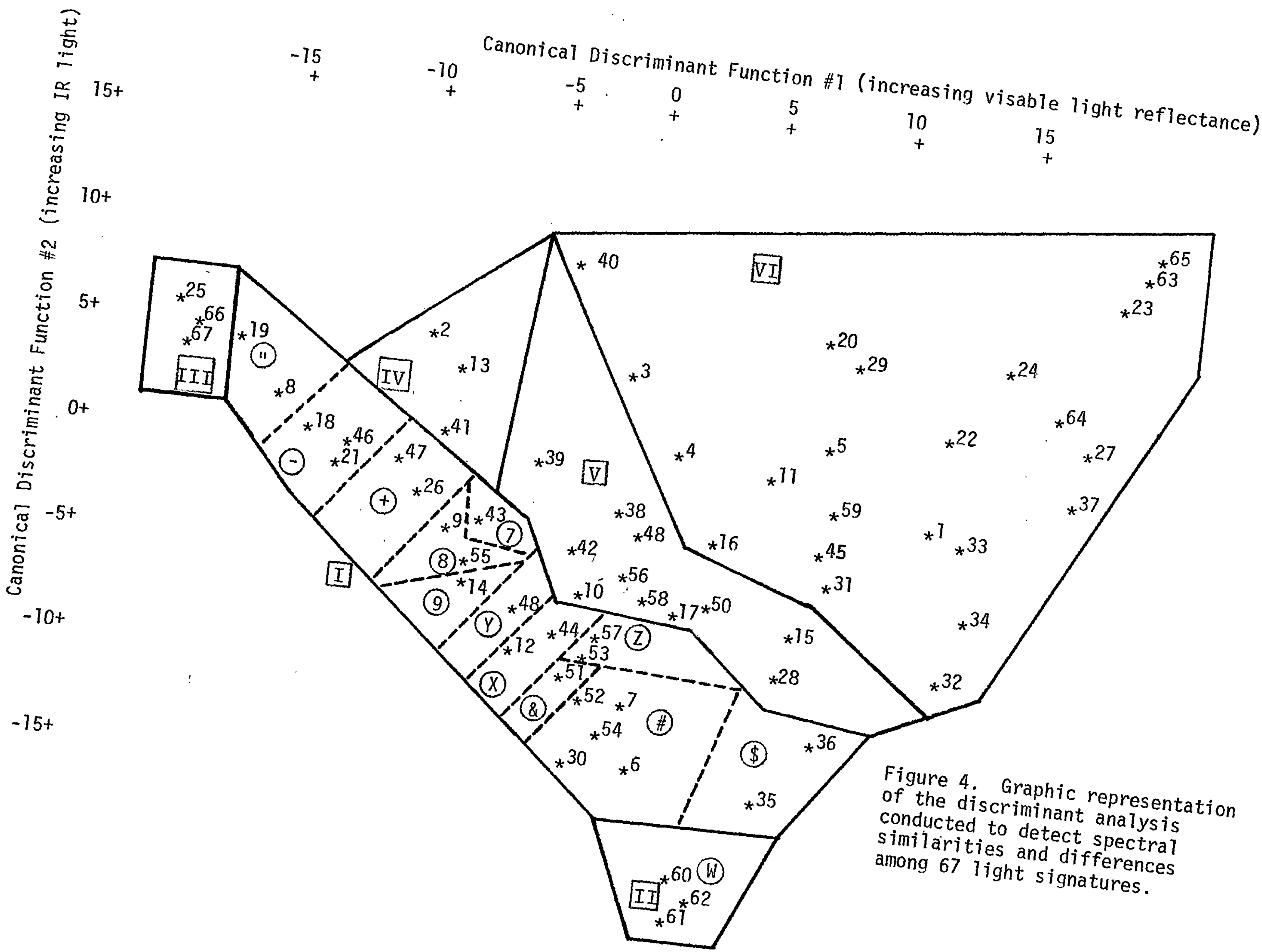


Figure 4. Graphic representation of the discriminant analysis conducted to detect spectral similarities and differences among 67 light signatures.

which is diagnostic of wet meadow or irrigated agriculture areas; signature #61 (lower center) has very low reflectance of infrared and moderately low reflectance of visable light which would mean that it represents water or shadow areas. Of course, the discriminant analysis provides information, besides Figure 4, which is helpful in the process of understanding relationships among signatures; the analysis quantitatively assesses the integrity of the signature groups created by the cluster analysis which helps in the process of deciding whether to combine two signatures into one group or leave them separate.

Preliminary digital print maps were produced for portions of the study area, with a unique pixel classification symbol assigned to each signature in Figure 4. As such print maps were compared with available field data and interpretations from aerial photographs and spectral curves, it was possible to partion the 67 signatures in Figure 4 into six major regions, only one of which is the focus of this study. The following provides a brief interpretation of the six major regions in Figure 4: Region I, aspen, conifer, and aspen/conifer mix forests; Region II, surface water and shadow; Region III, wet meadows, shrubs (i.e. principally maple) and some irrigated agriculture; Region IV, relatively moist areas dominated by herbaceous vegetation with scattered trees; Region V, relatively dry areas dominated by herbaceous vegetation, sometimes with scattered trees; Region VI, a variety of unforested areas from grass/forb meadows to bare soil or rock areas.

Once Figure 4 was partitioned into regions, further study focused exclusively on Region I. Examination of field sites and photo sites matching the individual signatures within Region I of Figure 4, in

addition to the study of signature shapes and results from the discriminant analysis, led to the creation of sub-regions within Region I. Once a decision was made to combine two or more signatures into one group, a common print character was assigned to all signatures so that on subsequent print maps pixels classified being in any one of the group of signatures appeared the same. Figure 4 shows the signatures included in sub-regions selected and the print symbol assigned. Table 1 presents the mean reflectance values for the four Landsat spectral bands for each forest group (the "W" or water group is also included since it is useful in registering print maps to base topographic or orthophoto maps). Note that the process of combining signatures does not merge the signature statistics in any way, but simply involves assigning a common print character to more than one signature. Thus, the mean band values in Table 1, where more than one signature is included for a given map symbol, represent an average of the individual signature mean values presented in Appendix A; the mean band values for the signatures have been combined in this manner to simplify the graphical presentation of the signatures.

Light signature curves for the map symbols in Table 1 and Region I of Figure 4 are presented in Figures 5 and 6. These signatures reflect a gradient of changing signature shape from map symbol '„' to symbol "$"; examination of aerial photographs and available field site information suggest that this spectral gradient corresponds with a forest gradient which begins with aspen forests and proceeds to coniferous forests, with various aspen/conifer mixes in between. Three types of aspen forest, represented by symbols '"', "-", and "+" have been discussed in an earlier study (Merola and Jaynes 1982); since this study has focused on identifi-

Table 1. Mean values of reflectance for four Landsat spectral bands for the groups mapped.

Map Symbol	Signatures Included	Landsat Spectral Bands			
		4	5	6	7
7	43	18.1	16.8	51.8	63.1
8	9, 55	16.4	14.6	49.0	60.6
9	14	16.0	13.6	45.2	57.6
X	12, 44	15.6	13.2	41.1	51.0
Y	48	16.2	14.7	41.1	50.0
Z	53, 57	16.7	16.1	39.2	46.1
&	51	14.7	12.8	35.7	43.5
-	18, 21, 46	16.9	14.4	59.3	75.7
"	8, 19	17.7	15.3	65.8	87.1
+	26, 47	17.8	15.6	55.8	69.0
#	6, 7, 30, 52, 54	14.1	11.9	30.7	36.9
$	35, 36	17.5	15.9	24.9	25.9
W	60, 61, 62	29.5	28.8	17.3	6.3

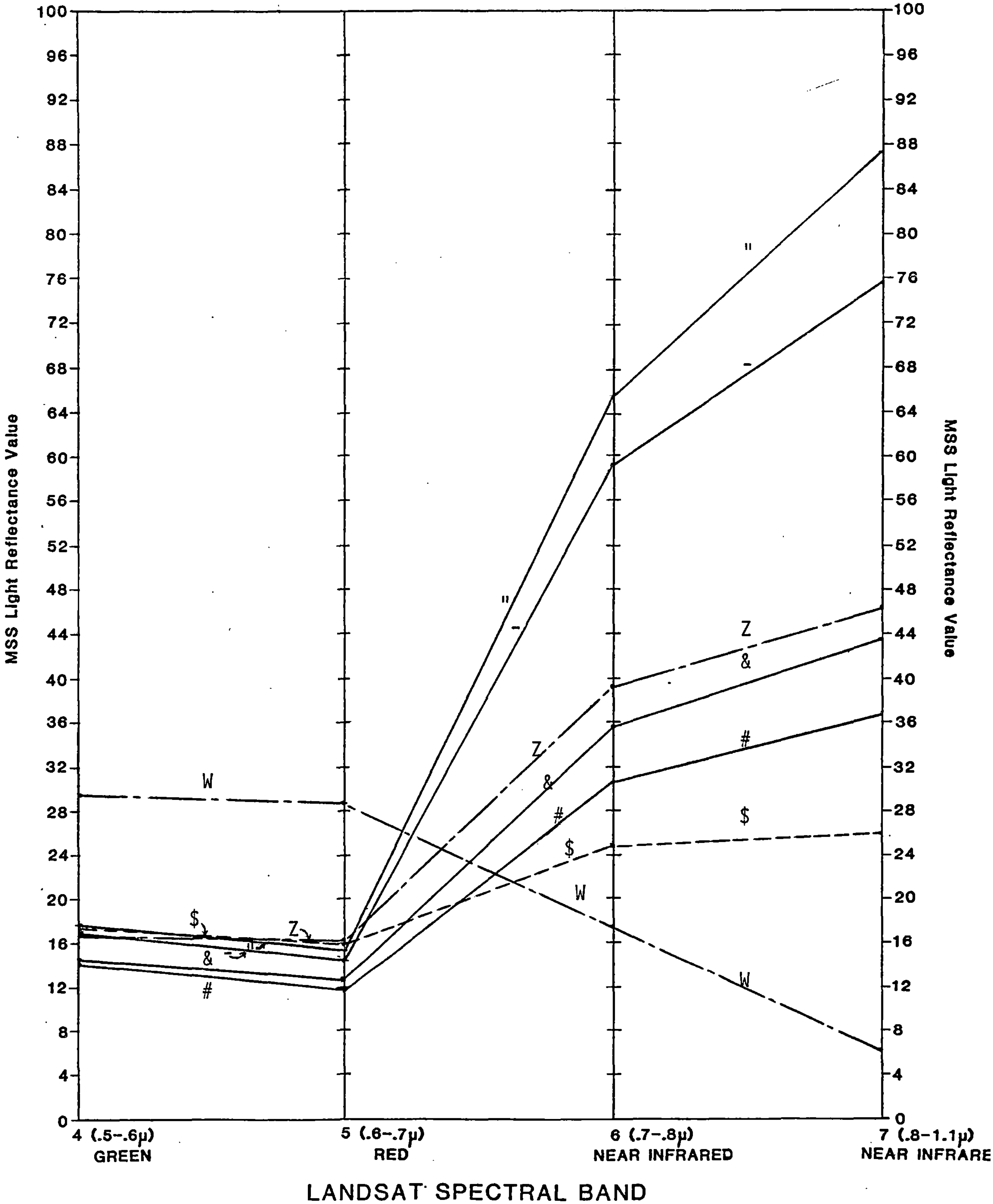


Figure 5. Light signature curves based on the group mean values shown in Table 1. The vertical axis represents reflectance values for the three different classes of pixels, as obtained from Landsat MSS data. The four points on the horizontal axis correspond to the spectral bands recorded by Landsat, with associated electromagnetic energy wavelengths in microns (10^{-6}m).

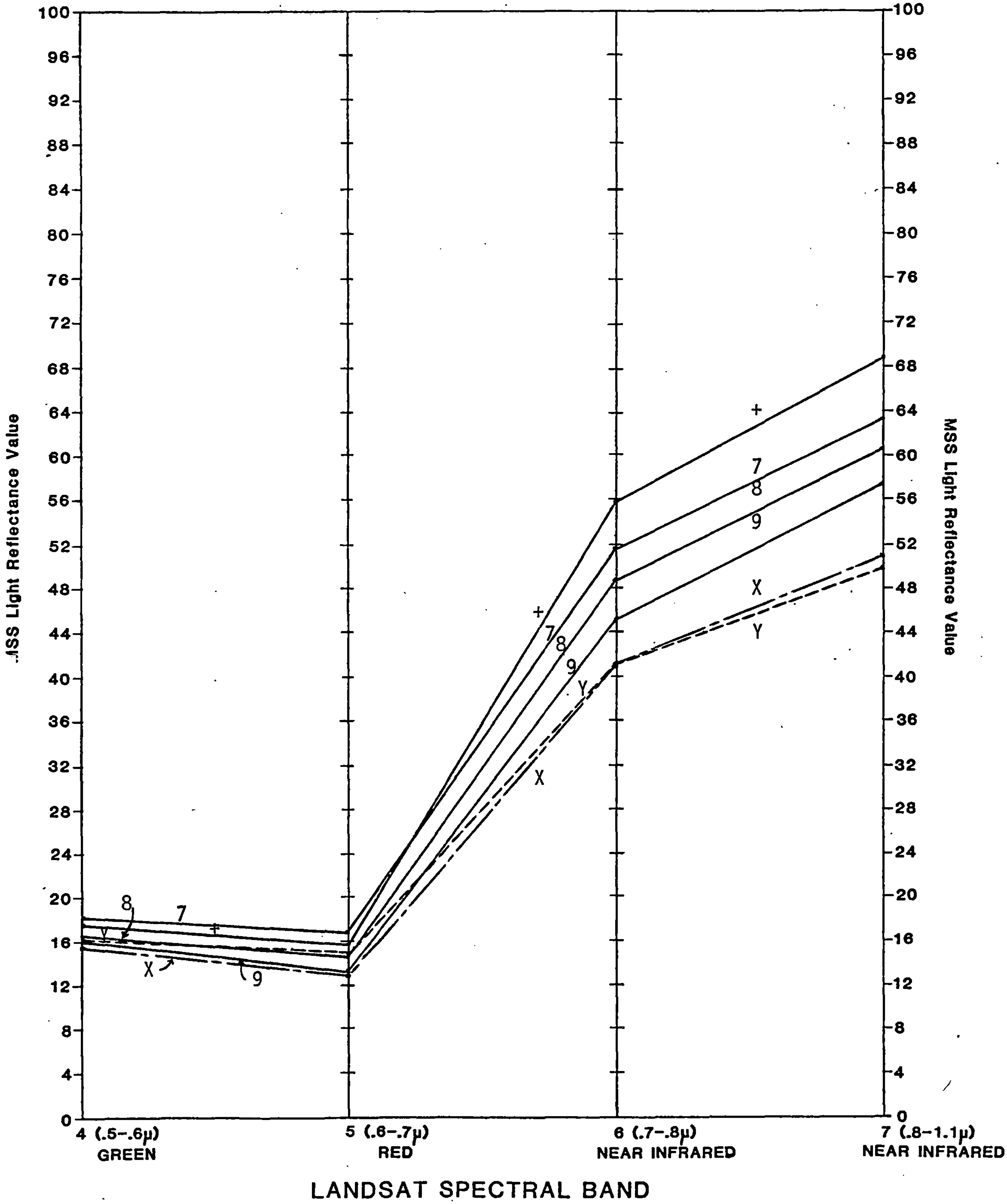


Figure 6. Light signature curves based on the group mean values shown in Table 1. The vertical axis represents reflectance values for the three different classes of pixels, as obtained from Landsat MSS data. The four points on the horizontal axis correspond to the spectral bands recorded by Landsat, with associated electromagnetic energy wavelengths in microns (10^{-6}m).

cation of aspen/conifer forest mixes, no further analysis of such maps symbols is presented here. Map symbol "#" (conifer forest) shown in Figure 5, has received relatively minor emphasis in this study but is included to complete the aspen to conifer spectral gradient. Map symbol "#" along with map symbol "$" (scattered conifers on north facing slopes) and "W" (water and shadow) have been included in the digital print map overlays to aid in registration to base maps. Map symbol "&", which was found generally to be associated with patchy or sometimes scattered conifers (with some aspen) adjacent to coniferous forest areas, has also been included as an aid in map registration.

The majority of interpretive effort was spent in obtaining photo interpretations of six map symbols which represent various forest mixes of aspen and conifer. A total of 102 photo sites were selected by identifying four or more pixels of the same signature per site on digital print maps, and then locating the same areas on aerial photography. Since the print maps were scaled to overlay onto the orthophoto quads, the task of finding photo sites was simplified. Table 2 presents the results of such interpretations for map symbols "7, 8, 9, X, Y, and Z"; note that the photo interpretations concentrated on overstory composition, canopy closure, and the plant life form for understory or vegetation in forest openings.

The observations summarized in Table 2 provided the basis for the print symbol interpretations in the map legend, shown in Figure 7. Print symbols "7, 8 and 9" exhibit a tendency toward a dominance of aspen within the forest mix; print symbols "X, Y and Z" tend toward conifer dominance. The trends in the light signatures shown in Figures

Table 2. Summary of aerial photography interpretations regarding overstory composition, canopy closure, and understory or vegetation in forest openings for six map symbols representing aspen and conifer mixes.

Map Symbol	No. of Photo Sites	OVERSTORY COMPOSITION 1/	CANOPY CLOSURE 2/	UNDERSTORY OR VEGETATION IN FOREST OPENINGS 3/
7	9	M-Aspen	CFO	S/F/G
	2	E	CFO	G/F
	2	M-Aspen	CFO	G/F
8	8	E	CC	-
	2	E	OC	S/F
	4	M-Aspen	OC	G/F
	3	M-Aspen	OC	G/F
9	5	E	CFO	S
	2	M-Aspen	CFO	G/F
	2	E	CFO	G/F
	3	E	CC	-
	3	M-Aspen	CC	-
X	9	M-Conifer	CC	-
	11	E	OC	S/F/G
	5	E	OC	S/F/G
	5	E	CC	-
Y	11	M-Conifer	OC	G/F
Z	3	E	OC	G/F
	7	M-Conifer	CFO	S/F/G
	6	E	CFO	S/F/G

1/ Relative composition (5) of forest canopy: M=mostly (i.e. greater than 60%) aspen or conifer; E= even (i.e. between 40% to 60% each) aspen and conifer.

2/ Forest canopy closure: CC= closed canopy, understory hardly visable; OC= open canopy, understory visable through tree-to-tree openings; CFO= closed canopy with forest openings, trees are close but forest has relatively large openings which allow a view of the understory.

3/ Understory and/or ground vegetation visable in forests with open canopy or closed canopy with forest openings: S/F/G= shrub-forb-grass; S/F= shrub-forb; G/F= grass-forb; S=shrub.

LEGEND

7 ASPEN/CONIFER MIX

8 ASPEN/CONIFER MIX

9 ASPEN/CONIFER MIX

X CONIFER/ASPEN MIX

Y CONIFER/ASPEN MIX

Z CONIFER/ASPEN MIX

& CONIFER/ASPEN MIX

Forest mixes are in order of increasing amounts of conifer canopy cover relative to aspen canopy cover

- ASPEN FOREST, HIGH QUALITY[1]

" ASPEN FOREST, MEDIUM QUALITY[1]

+ ASPEN FOREST, LOW QUALITY[1]

CONIFER FOREST

$ SCATTERED CONIFER *(ON NORTH FACING SLOPES)*

W WATER

[1] Discussion of these classes can be found in CRSC Report 82-2

Figure 7. Legend for the aspen-conifer forest succession map overlays.

5 and 6 suggest that the series of map symbols "7, 8, 9, X, Y and Z" should be correlated with increasing levels of conifers in the overstory composition; although photo interpretation did not allow a precise measurement of canopy composition to verify this trend directly, the information in Table 2 suggests that other factors may be involved in creating the spectral differences among the forest habitats mapped. For example, map symbol "7" was associated with closed canopies with forest openings whereas map symbol "8" was found to have either a closed or open canopy. As the digital print maps, an example of which is shown in Figure 8, are field verified, greater insights into the relationships between ground characteristics and spectral attributes will be gained. It seems clear, however, that Landsat is able to separate out aspen and conifer mixes from pure aspen and pure conifer stands. It would appear from information presently available that map symbols "7, 8 and 9" represent mid seral forests and map symbols "X, Y and Z" represent late seral forest situations.

One of the advantages of having resource maps, such as Figure 8, in digital form is that it allows computer tabulation of areas covered by selected map classes. Table 3 presents the acreage tabulation of the map symbols shown in Table 1 for each quadrangle in the study area.

Figure 8. Portion of the Paris Peak U.S.G.S. quadrangle overlay (scale 1:24,000) of aspen/conifer forest succession overlays.

Table 3. Area tabulations for aspen, conifer and mixed forest groups for the regions mapped on each U.S.G.S. quadrangle. Map symbols correspond to the signatures in Figures 5 and 6, and the legend descriptions in Figure 7.

		Map Symbols											
State	USGS Quadrangle	"	-	+	7	8	9	X	Y	Z	&	#	$
Idaho	Mink Creek	1,158	2,190	1,857	892	1,835	925	1,433	202	272	397	804	11
	Paris Peak	293	1,182	1,357	896	1,442	759	1,337	759	1,813	754	4,495	291
	Paris	115	377	467	408	426	295	408	161	198	156	186	2
	Mapleton	260	1,165	1,619	939	1,639	841	1,353	353	802	471	2,640	283
	Egan Basin	188	436	689	746	821	388	1,141	960	2,485	957	5,485	229
	St. Charles	109	253	402	409	417	351	803	471	951	688	2,405	26
Utah	Naomi Peak	232	449	904	780	830	531	845	363	892	437	2,912	766
	Tony Grove Creek	2,076	2,592	1,930	1,394	1,367	677	1,148	752	1,693	855	4,868	42
	Garden City	49	360	771	739	702	376	700	436	841	448	1,526	16
	Mt. Elmer	685	1,030	1,136	646	1,018	595	1,312	484	1,031	652	3,710	710
	Temple Peak	1,703	3,382	2,120	1,550	2,445	983	1,157	592	1,058	507	2,864	121
	Meadowville	482	1,618	1,327	848	1,333	759	1,168	421	695	742	3,192	27
	Logan Peak	2,166	2,638	1,667	891	1,522	841	1,473	390	1,094	634	2,915	282
	Boulder Mtn.	2,071	4,301	2,820	1,475	1,540	583	652	340	492	145	558	30
	Red Spur Mtn.	310	975	1,133	944	1,282	609	951	472	546	482	1,503	15

CONCLUSION

Aspen, conifer and mixed aspen/conifer forests have been mapped for a 15-quadrangle study area in the Utah-Idaho Bear River Range using Landsat multispectral scanner data. Digital classification of Landsat data allowed the identification of six groups of signatures which reflect different types of aspen/conifer forest mixing. Photo interpretations of the print symbols suggest that such classes are indicative of mid to late seral aspen forests. Further field verification is needed to acquire additional information about the nature of the forests which have been examined via remote sensing. Since aspen canopies tend to obscure understory conifers for early seral forests, a second date analysis, using data taken when aspens are leafless, could provide information about early seral aspen forests. This study suggests that single date Landsat analysis will be a cost effective means to index aspen forests which are at least in the mid seral phase of conifer invasion.

LITERATURE CITED

Bartos, Dale L. 1973. A Dynamic Model of Aspen Succession. In IUFRO Biomass Studies, Univ. Maine Press, Orono (p. 11-25).

Green, A. W., and T. S. Setzer. 1974. The Rocky Mountain Timber Situation, 1970. USDA Forest Service Resource Bulletin INT-10. Intermountain Forest and Range Experiment Station, Ogden, Utah.

Hutchinson, Charles F. 1982. Techniques for Combining Landsat and Ancillary Data for Digital Classification Improvement. Photogrammetric Engineering and Remote Sensing, Vol. 48, No. 1: 123-130.

Mayer, Kenneth E., and Lawrence Fox III. 1981. Identification of Conifer Species Groupings from Landsat Digital Classifications. Photogrammetric Engineering and Remote Sensing, Vol. 48, No. 11: 1607-1614.

Merola, John A. and Richard A. Jaynes. 1982. Detection of Variations in Aspen Forest Habitat from Landsat Digital Data: Bear River Range, Utah. Center for Remote Sensing and Cartography Report 82-2. 31 p.

Mueggler, Walter F. 1976. Type Variability and Succession in Rocky Mountain Aspen. In Proc. Utilization and Marketing as Tools for Aspen Management in the Rocky Mountains Symp., USDA Forest Service Gen. Tech. Report RM-29. Rocky Mt. For. and Range Exp. Stn., Ft. Collins, Colorado, p. 16-19.

Todd, W. J., D. G. Gehring, and J. F. Haman. 1980. Landsat Wildland Mapping Accuracy. Photogrammetric Engineering and Remote Sensing, Vol. 46: 509-520.

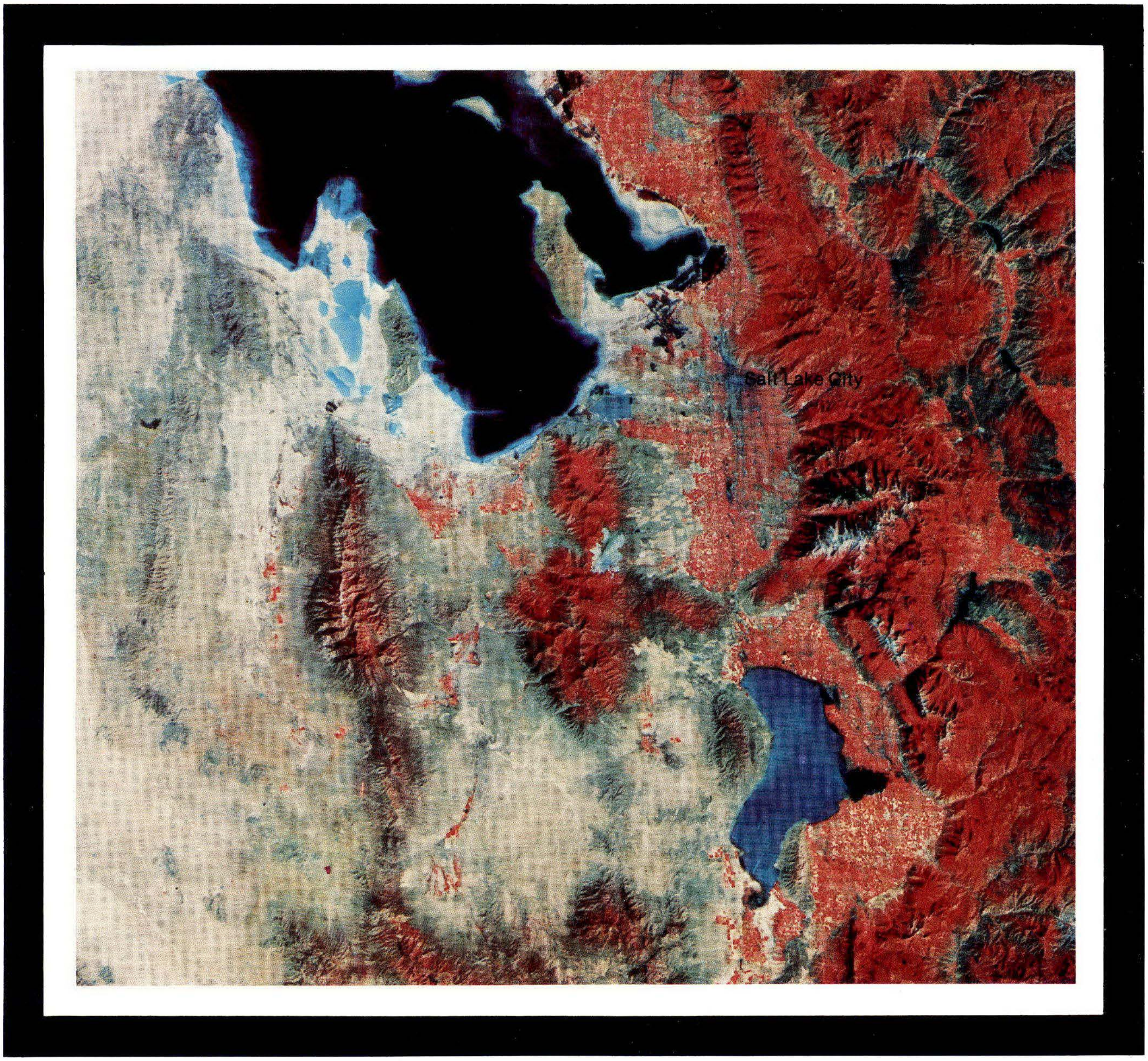
Tom, Craig H., and Lee D. Miller. 1980. Forest Site Index Mapping and Modeling. Photogrammetric Engineering and Remote Sensing, Vol. 46, No. 12: 1585-1596.

Appendix A. Mean spectral band reflectance values for the 67 light signatures used in this study.

Signature Number	Landsat Spectral Bands 1	2	3	4
STAT 1	29.16	33.29	47.82	49.38
STAT 2	23.22	23.00	68.67	85.11
STAT 3	26.11	29.22	62.00	74.78
STAT 4	24.78	27.33	55.44	63.89
STAT 5	29.00	34.17	56.94	61.17
STAT 6	13.57	11.42	27.17	32.79
STAT 7	15.70	14.16	33.77	39.87
STAT 8	17.20	14.67	63.83	83.05
STAT 9	16.48	14.19	49.54	62.07
STAT 10	18.09	17.46	43.98	51.72
STAT 11	25.89	29.67	53.33	57.44
STAT 12	15.16	12.14	39.71	48.86
STAT 13	22.83	21.44	65.33	78.33
STAT 14	16.00	13.61	45.22	57.56
STAT 15	22.06	23.47	39.47	42.25
STAT 16	23.06	23.42	47.31	52.28
STAT 17	19.67	18.53	39.06	45.03
STAT 18	17.00	14.23	60.02	78.23
STAT 19	18.11	15.80	67.81	91.06
STAT 20	32.78	38.89	66.78	72.33
STAT 21	16.16	13.24	57.00	73.53
STAT 22	31.59	39.19	55.74	57.93
STAT 23	40.44	52.22	67.00	66.78
STAT 24	35.67	43.11	60.33	63.67
STAT 25	18.06	15.22	72.83	97.22
STAT 26	17.56	15.18	54.72	67.50
STAT 27	35.22	43.00	52.89	52.67
STAT 28	20.67	21.06	34.06	37.89
STAT 29	31.44	35.89	62.44	67.11
STAT 30	12.59	9.52	29.00	35.19
STAT 31	24.81	26.67	43.11	46.50
STAT 32	25.22	27.11	34.56	33.89
STAT 33	28.78	33.70	44.56	45.37
STAT 34	27.28	31.44	38.78	38.94
STAT 35	15.78	13.33	22.00	24.22
STAT 36	19.11	18.44	27.67	27.56
STAT 37	33.33	39.11	48.44	47.00
STAT 38	21.38	22.27	51.04	60.11
STAT 39	21.42	22.67	57.14	67.89
STAT 40	28.00	31.56	74.33	86.11
STAT 41	20.17	19.67	59.61	74.22
STAT 42	18.78	18.89	47.06	56.44
STAT 43	18.11	16.78	51.81	63.06
STAT 44	15.93	14.22	42.53	52.96
STAT 45	24.44	29.11	46.22	48.89
STAT 46	17.56	15.83	60.94	75.28
STAT 47	17.96	16.00	56.80	70.51
STAT 48	16.17	14.72	41.11	49.96
STAT 49	20.89	22.78	48.22	56.89
STAT 50	20.44	22.67	42.00	47.67
STAT 51	14.69	12.84	35.72	43.49
STAT 52	14.06	12.39	32.64	39.94
STAT 53	16.63	14.67	37.59	45.48
STAT 54	14.37	12.09	30.91	36.50
STAT 55	16.33	14.89	48.50	59.06
STAT 56	19.33	21.44	45.67	53.89
STAT 57	16.67	17.44	40.67	46.67
STAT 58	18.89	19.67	40.78	49.56
STAT 59	26.67	31.44	48.56	53.78
STAT 60	15.44	13.22	10.39	4.17
STAT 61	33.94	34.14	19.67	7.08
STAT 62	39.28	38.96	21.80	7.57
STAT 63	38.53	49.32	59.58	57.56
STAT 64	29.78	38.22	64.89	72.89
STAT 65	54.67	66.67	87.00	86.11
STAT 66	18.33	16.33	69.00	94.33
STAT 67	16.67	13.89	70.44	92.89

CENTER FOR REMOTE SENSING AND CARTOGRAPHY

UNIVERSITY OF UTAH RESEARCH INSTITUTE



Salt Lake City, Utah, and vicinity as seen from the LANDSAT 1 satellite. This photograph is a color infared composite from the multispectral sensor's bands 4, 5, and 7 taken on August 7, 1972. The red color indicates healthy green vegetation. Forests, irrigated cropland, dryfarms, lakes, reservoirs, wetlands, deserts, rangelands, cities, highways, mining operations, and other features are visible on this scene, taken from an altitude of 570 miles (920 km) above the earth.

PURPOSE

Modern pressures to both develop and conserve our land, natural, and environmental resources create the need for public, private, and international decision makers to maximize understanding of the nature of each management problem. Limited time and scarce financial resources demand that efficient approaches to land and resource management problems be readily available. In light of such information requirements, remote sensing is becoming increasingly useful as a modern scientific technology which utilizes various photographic and electronically sensed data to extend the "ground truth" available from a small area to much larger areas.

The people at the Center for Remote Sensing and Cartography (CRSC) see themselves as a team of specialists dedicated to providing decision makers with the timely and cost-effective information needed to make important decisions wisely. We are convinced that as management information needs are discussed within the context of state-of-the-art remote sensing technology, improved approaches to the study and planning of management alternatives will be forged. From our own personal perspective, assisting in the process of earth resource decision-making also allows us to experience the satisfaction of augmenting our own understanding of environmental systems and remote sensing technology. Participating in the process of natural resource and environmental policy and management decision-making provides us with the greatest incentive for performing remote sensing research.

CRSC STAFF

The CRSC staff is comprised of individuals with backgrounds in geography, natural resources management, cartography, biology, computer science, statistics and natural resource and environmental law.

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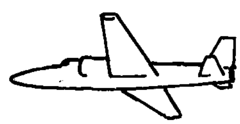
Research Analyst

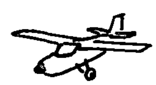
Keith F. Landgraf, B.S.
Research Analyst

MULTI-STAGE RESOURCE ANALYSIS

Satellite Imagery (570 mi.) (920 km)



U-2 Color Infrared Photography (60,000 ft.) (18,300 m)



Low Elevation Photography (variable altitude)

Field Investigation

FUNCTION

CRSC was created to establish a highly specialized technical facility capable of performing techniques research and development, and applied project research across a broad range of remote sensing and mapping needs. Base funding provided by the National Aeronautics and Space Administration (NASA) since 1976 has allowed CRSC to become involved in applied research on practical resource management problems for public agencies, demonstrating the utility of satellite and airborne remote sensing systems. Service and research are available on contract to local, state, and federal agencies, to industry, international clients, and universities. Our association with the University of Utah Research Institute, a non-profit corporation, allows us to expand our operational capabilities to include those of the Institute with minimal cost.

CRSC's resource management and planning projects generally involve one or more of the following areas of investigation:

1. Land use/land cover mapping
2. Integrated natural resources inventory and analysis
3. Environmental monitoring and impact assessment
4. Environmental hazard analysis
5. Detection of land pattern changes over time

The typical multi-stage approach of CRSC to earth resource analysis is illustrated by the column of figures to the left. Satellite imagery, high-altitude aircraft infrared photography, and conventional aerial photography are commonly used in varying combinations, together with ground reconnaissance and field investigation, to arrive at the final product. The analysis of satellite multi-spectral digital data may be augmented through combining with terrain and other digital data. Digitization of a variety of thematic data permits CRSC staff to perform overlay compositing and Geographic Information System (GIS) mapping and analysis.

Job specifications are tailored to specific resource management problems ranging from experimental research to routine inventory and mapping. CRSC works closely with the client from the conception of each project through field and laboratory operations to project completion. Final products typically include a combination of digital and/or conventional maps or overlays, col displays and graphics, and analytical research reports.

CAPABILITIES AND EXPERIENCE

Digitizing and computer facilities provide a highly automated, integrated system for land pattern recognition, classification, and mapping. Computer programs for classification and mapping of land use and environmental factors are among the fastest and most reliable systems available. Use of these programs on the Institute's Prime and the University of Utah's Univac computers keep time and cost to a minimum. Storage and retrieval of land use and environmental data, together with rapid acquisition of new data through satellite time-sequenced imagery and aircraft photography simplify the usually laborious and costly updating problem involved in most land use, crop inventory, and resource mapping programs.

EXAMPLES OF PROJECT WORK INVOLVEMENT

LAND USE/COVER — Tooele County, Utah. Landsat photo image analysis of terrain as related to resource and land planning (for Mountain Area Planners, Inc.)

IRRIGATION DETECTION — Southwest Utah. Detection and mapping of unlawful irrigation from Landsat photo images (for Utah Divison of Water Rights)

SNOWPACK/RUNOFF — Northern Utah. Landsat image interpretation of snow area for runoff forecasting (for Utah Division of Water Resources and Soil Conservation Service)

SNOWPACK/MULE DEER — Central Utah. Landsat image measurement of snow cover related to winter mortality of deer (for Utah Division of Wildlife Resources)

HAZARDS TO URBAN GROWTH — North Ogden, Utah. Mapping of flood, fault, and deer habitat factors, and geomorphologic units from low and high altitude aircraft photography, with compositing of maps utilizing manual and computer techniques (for cities of North Ogden and Pleasant View)

INTEGRATION of LANDSAT with HAZARD MAPS — Farmington, Utah. Digital integration of Landsat-derived agricultural land use with natural hazard data (with Federation of Rocky Mountain States)

FOOTHILL DEVELOPMENT — Davis County, Utah. Analysis and mapping of hillside geomorphology and vegetation from low altitude black and white, and high altitude color infrared photography for use in a model foothill development ordinance (for Davis County)

SHORELINE FLUCTUATION — Great Salt Lake, Utah. Digital mapping of fluctuating shoreline and waterfowl habitat for management and planning from satellite data and aircraft photography (Utah Division of Wildlife Resources)

WATERFOWL HABITAT CHANGES — Great Salt Lake, Utah. Analysis of Landsat digital data and color infrared photography to evaluate the effects of lake shoreline fluctuations on waterfowl habitat (Utah Division of Wildlife Resources)

WETLAND MAPPING — Uinta Basin, Utah. Landsat digital data and high altitude photography classification and mapping of wetlands and water-related land use (for Soil Conservation Service and Utah Division of Water Resources)

ASPEN HABITAT TYPES — Bear River Range, Utah. Use of Landsat digital data correlated with forest understory composition to classify a variety of aspen habitats (for Cache National Forest)

GUAYULE DETECTION — Coahila, Mexico. Digital contrast enhancement of Landsat image to detect presence of guayule (rubber-containing shrub) for production (Mexcian government)

GUAYULE INVENTORY — Coahila, Mexico. Landsat digital analysis and contrast enhancement for regional mapping of guayule habitats (Mexican government)

REGIONAL LAND USE — South and North Korea. Eighteen color maps of land use digitally mosaiced and trimmed on quad base from satellite data (for South Korean government)

EQUIPMENT AND FACILITES

COMPLETE CARTOGRAPHIC/PHOTOGRAPHIC/LITHOGRAPHIC CAPABILITIES

- Conventional cartographic production
- Negative engraving, color keying, etc.
- Process camera, photo mechanical transferring
- Contact printing, photographic enlarging
- Slide and viewgraph production

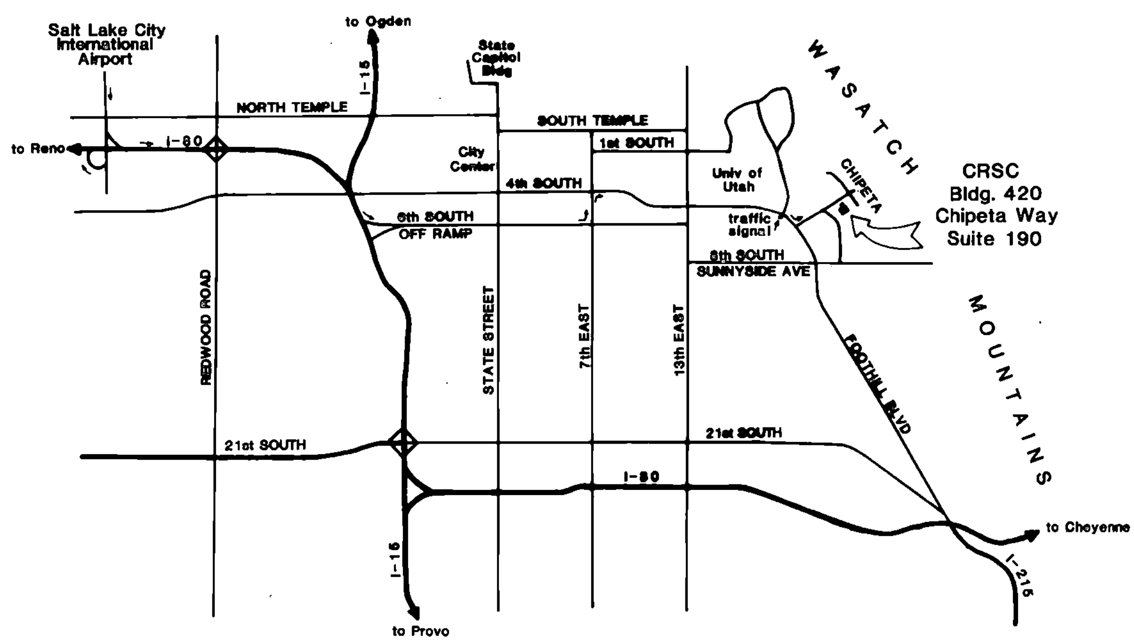
FULLY INTEGRATED REMOTE SENSING/COMPUTER MAPPING CAPABILITIES

- Baush & Lomb zoom stereoscope
- Power zoom station for roll film analysis
- Multispectral image compositor
- Interactive color display system
- Precision color display scope for highly detailed color work
- Color camera system coupled with film writer
- Microdensitometer, array processor
- Map digitizer and computer planimeter
- Library of computer mapping routines (Harvard, NASA, etc.)
- Composite computer mapping programs (NASA, University of Utah, etc.)
- Complete digital processing of NASA satellite computer tapes, including supervised and unsupervised classification, various statistical analyses and plots, georectification and mapping, custom scaling, multitemporal overlaying, property ownership overlaying, integration of digital terrain data, and integration of digital thematic maps from multiple sources at multiple scales
- Geographic Information System mapping and analysis
- Computer contrast enhancement (custom contrast/color stretching)
- Computing capabilities based on Prime 400, PDP 11, and UNIVAC 1100-61

MAP AND IMAGE ACCESS

- Complete USGS and DMA quadrangles of the United States and most of the world
- Photograph and image coverage of Utah (B/W, U-2 CIR, Skylab, Landsat)
- Immediate access to world-wide satellite microfilm browse file through the national USDA Aerial Photograph Field Office in Salt Lake City

LOCATION MAP
Center for Remote Sensing and Cartography



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